Improving the use of satellite observations for ocean data assimilation with a reduced rank smoother

N. Freychet[1], E. Cosme[1], E. Kpemlie[2], P. Brasseur[2], J.-M. Brankart[2], J. Verron[2]
[1]*Joseph Fourier University/LEGI, Grenoble, France, Nicolas.Freychet@hmg.inpg.fr*
[2]*CNRS/LEGI, Grenoble, France*

Introduction

Data assimilation for oceanography widely use satellite observations such as altimetric tracks. Stochastics methods such as the Kalman filter often run sequentially: the numerical model propagates the ocean state through time, and an analysis is performed on a regular basis, using the available observations data. Such a configuration allows the use of past, present, but not subsequent observations. Then, for a given analysis, only tracks available at that time will be used, disregarding the forthcoming, sometimes complementary observations.

To improve the coverage of observation tracks for data assimilation, optimal smoothers might be introduced and allow the use of subsequent observations for a given analysis time. Here, the implementation of the SEEK smoother with a high resolution model configuration of the Tropical Atlantic ocean is presented. This region is of specific interest due to the presence of Tropical Instability Waves (TIWs): fast oscillations travelling from East to West, and difficult to track with a "forward-only" data assimilation method feeded with uncomplete observations such as along-track altimetric measurements. We present these aspects here.

I. Experimental scheme

I.1 Model and observations

We use a Tropical Atlantic configuration (TATL4) of the ocean model NEMO025 (figure 1). Two particular regions may be noted : the Tropical Instability Waves zone in the center of the bassin, and the North Brazil zone where eddies may develop.

Tests on the smoother are performed using twin experiments. A "true" sequence of ocean state is defined as year 2005. We extract observations from this year. An example is given in figure 2: satelites tracks of Sea Surface Height, SSH, (Jason type), and T/S profiles (profilers type ARGO).

A "false" state is built with an error on the initial condition. We first let the model equilibrate with the forcing fields during 2 months (in the beginning it converges quickly by his own); then, when the convergence slows down, we start assimilation experiment.

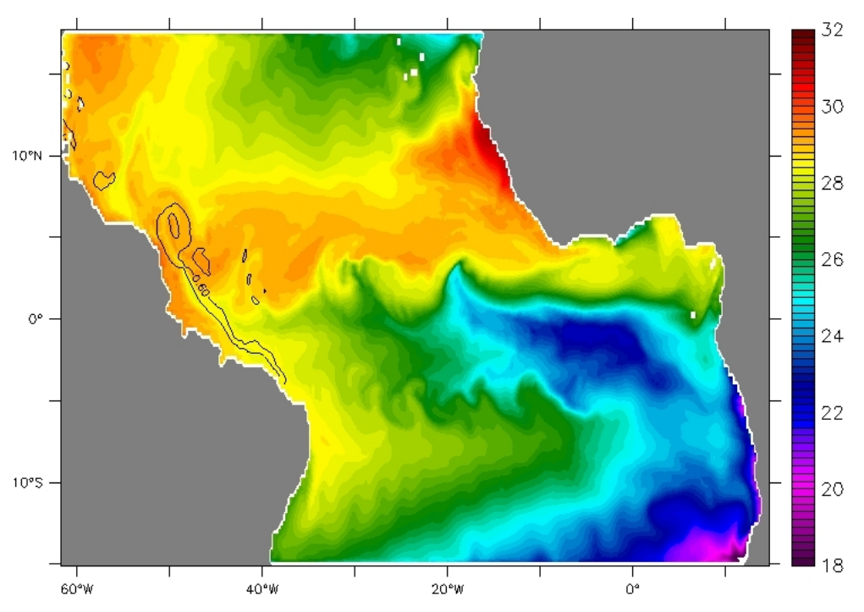


Figure 1 show the Tropical Atlantic configuration of NEMO model (TATL4). Surface temperature (colored) shows Tropical Instability Waves (TIWs). Velocity (black contour) shows the North Brazil current and a ring formed in the northest part.

I.2 Data assimilation experiment

The experiment starts on June 25 (Julian day 20252) and lasts 50 days. The false ocean state is analysed by the SEEK filter (Pahm 1998) using observations available every 2 days. A Kalman smoother (Cosme 2010) is applied and performs several retrospective analyses, using cross-time error statistics and observations distributed in time.

Figure 2 shows the altimetric observations available on June 25, as used by the filter for the ocean state estimation. Figure 3 shows the following satellite tracks used by the smoother for the estimation on the same day. The coverage of observations is improved thanks to the smoother.

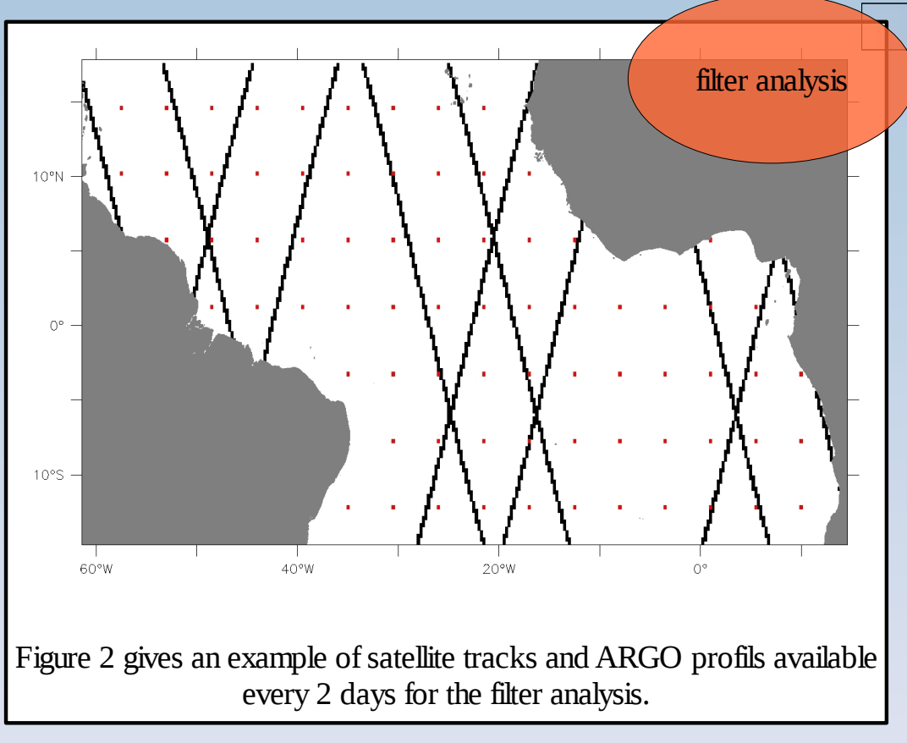


Figure 2 gives an example of satellite tracks and ARGO profils available every 2 days for the filter analysis.

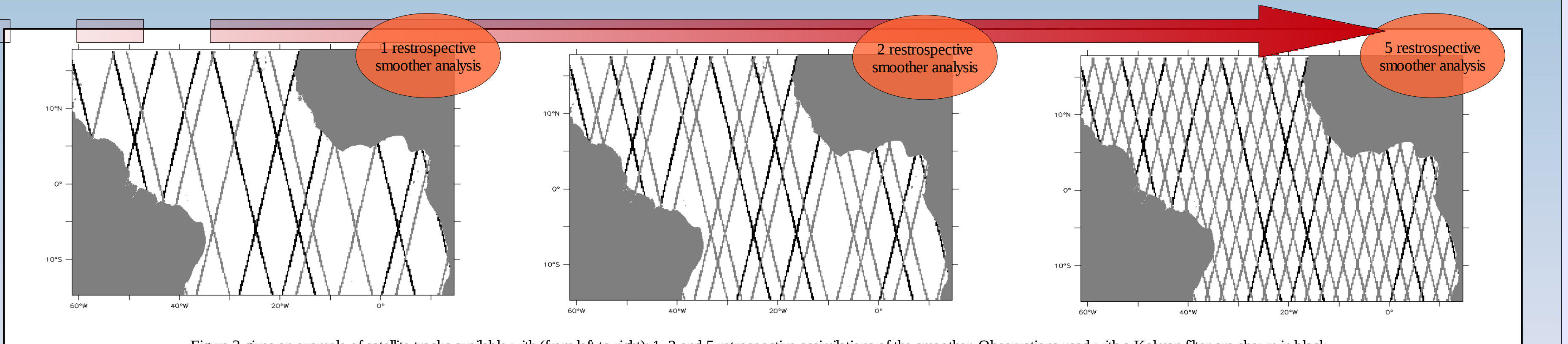


Figure 3 gives an example of satellite tracks available with (from left to right): 1, 2 and 5 retrospective assimilations of the smoother. Observations used with a Kalman filter are shown in black, and subsequent observations used with a Kalman smoother are shown in grey.

II. Results

II.1 Reducing global RMS error

The smoother has shown good skills to reduce globale RMS errors of assimilated variables (SSH, temperature and salinity) and of the dynamics (velocity). Figure 4 shows an example for the SSH and the meridional velocity. The smoothed reanalysis (black cross) are closer to the reference than the filtered solution (black line).

Figures 5 (a, b and c) shows some examples of the impact of the smoother. In a general point of view, the smoother impact is more obvious in the beginning of the experiment, when errors are the largest. It also leads to a more realistic representation of the equatorial under-current (in term of intensity).

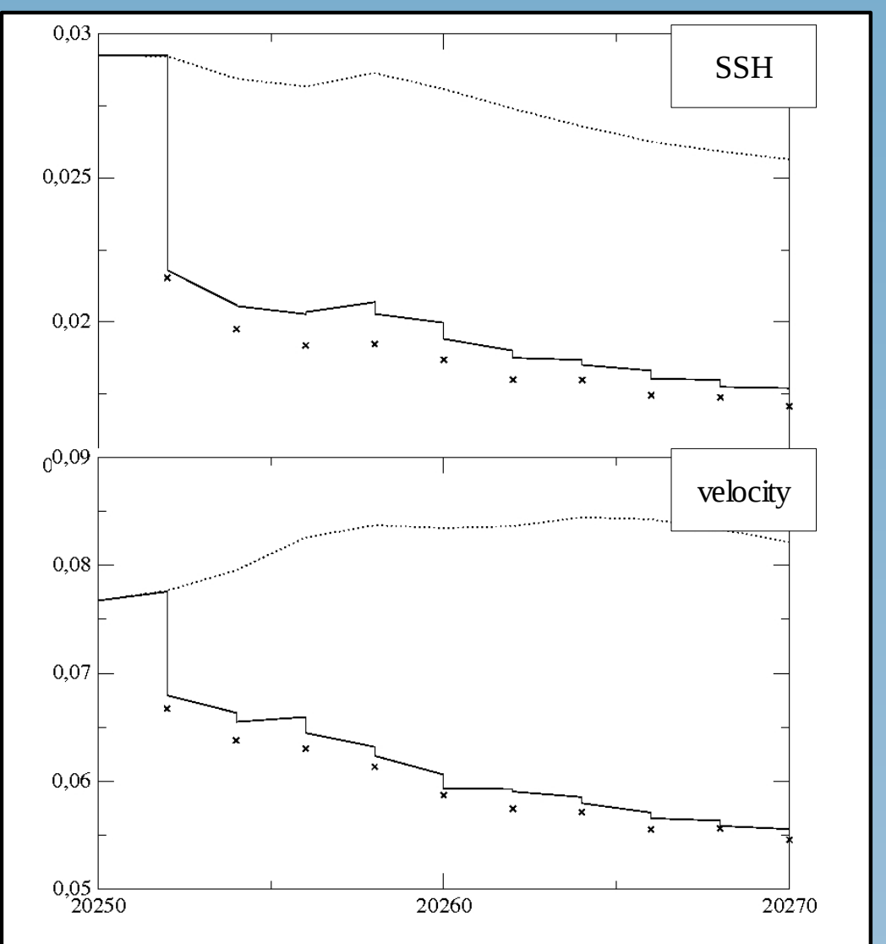
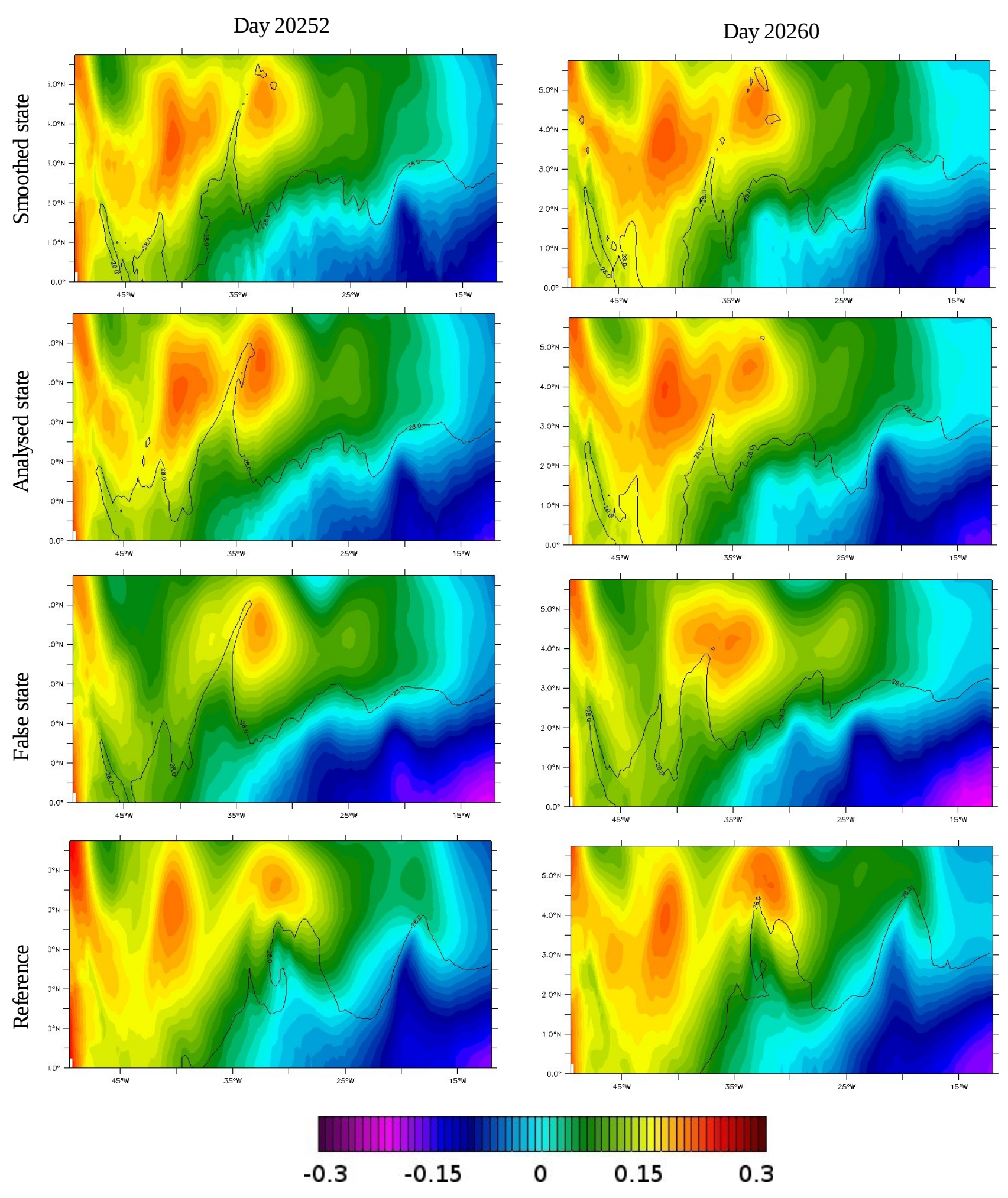


Figure 4 shows the RMS error for the SSH (top) and the meridonal velocity (bottom). The dashed line correspond to the false run, the full black line is the filtered solution and the black cross are the 5-retrospective smoothed solutions.

Figure 5 (a) shows the snapshots of SSH (in cm) at days 20252 (left) and 20260 (right) in the center of the bassin where TIWs may develop. The figures are given for (from bottom to top): the reference, the false run, the filtered run and the smoothed run.
The black line shows the 28°C contour, given an idea of the position of the TIW.



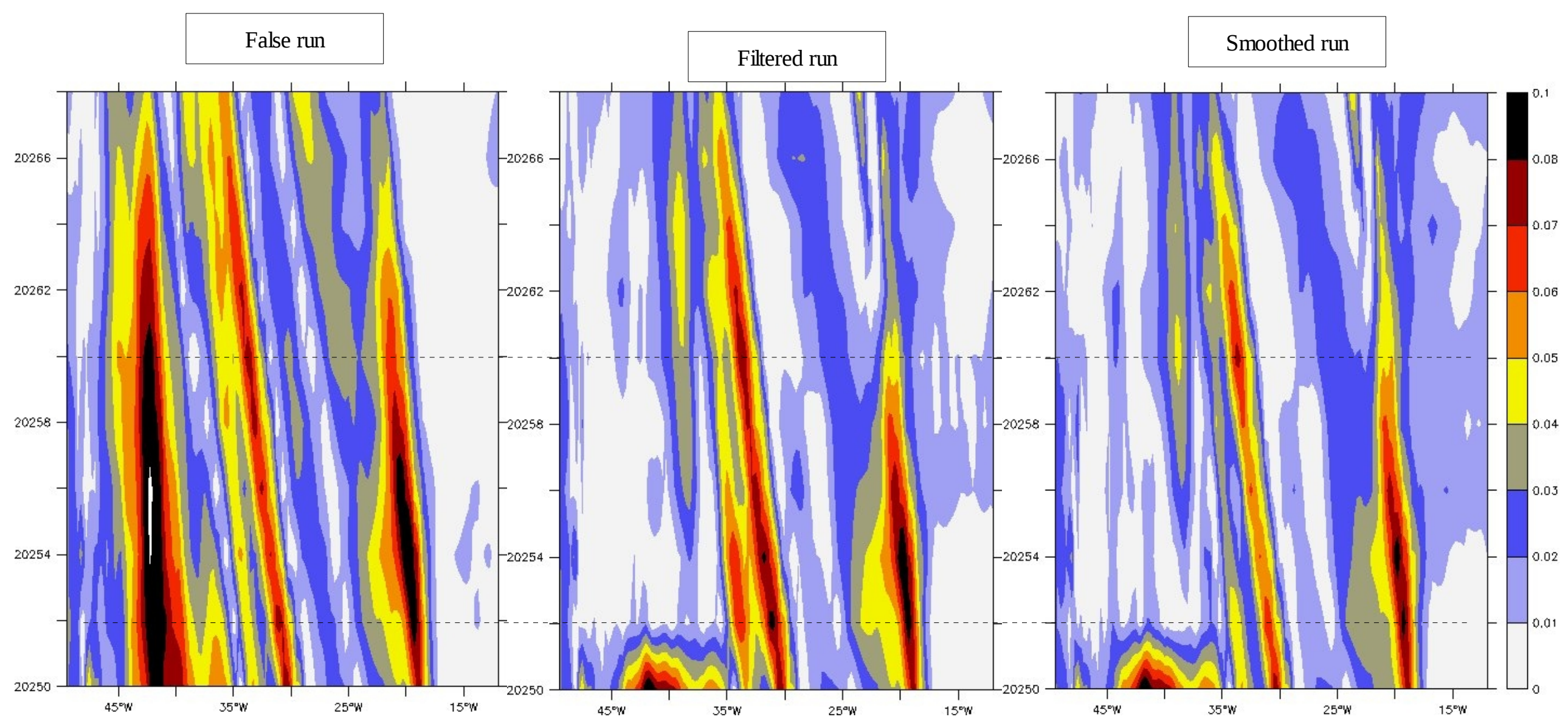


Figure 5 (b) shows the Hovmuller diuagrams for the SSH error (in cm). The dashed line notices the time to which the snapshot of figure 5 (a) are extracted/

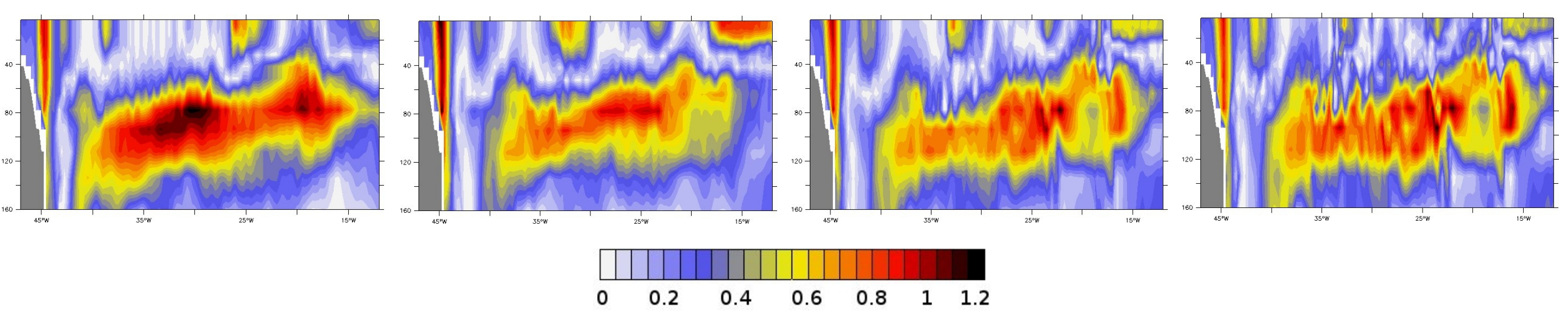


Figure 5 (c) shows the meridional velocity (in $m.s^{-1}$) at day 20252 along a vertical cross-section at the equator. Pictures are given for (from left to right) : the reference, the false run, the filtered run and the smoothed run.

II.2 Smoothing the analysed solution

The smoother increase the spatial coverage of observations at a given time. It is then able to produce analysis states more homogenous as shown on figure 5.

It is then a useful tool to produce reanalyses spatially smoothed. Thus the solution is more realistic and prevent potential inconsistent structures.

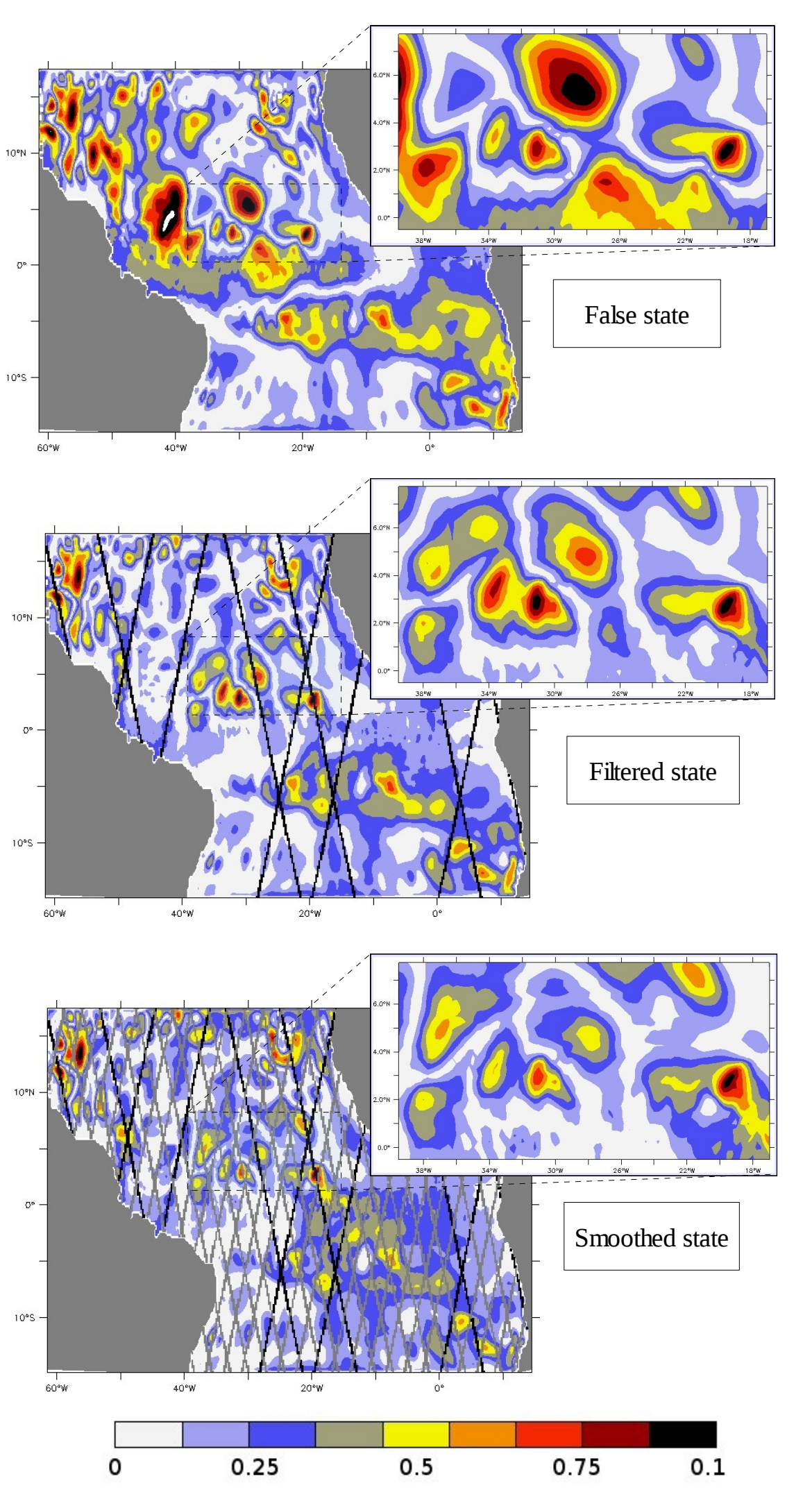


Figure 6 shows the SSH error (in cm) at day 20252 for the false state (top), the filtered state (middle) and the smoothed state (bottom). Assimilated SSH tracks for the filter and the smoother analysis are also shown (according to the figure 2 and 3). A zoom of a particular region where the smoother is quite effective is shown in the black boxes.

II.3 "Stability" of analysed states

We also tested the ability of analysed solutions (from the filter and the smoother) to represent the dynamics of the bassin. A simple test is carried out on that purpose: we used the analysed states to restart the model and we observed each trajectories (figure 7).

It is shown that the smoothed states are more consistent with the dynamics. The free runs initialised with the smoothed states show a trajectory closer to the reference, specially in the North Brazil zone where the dynamics is very sensitive to the initial condition. These results are consistent with the results II.2 that suggested that the smoothed solution provides solutions with more spatially homogeneous errors.

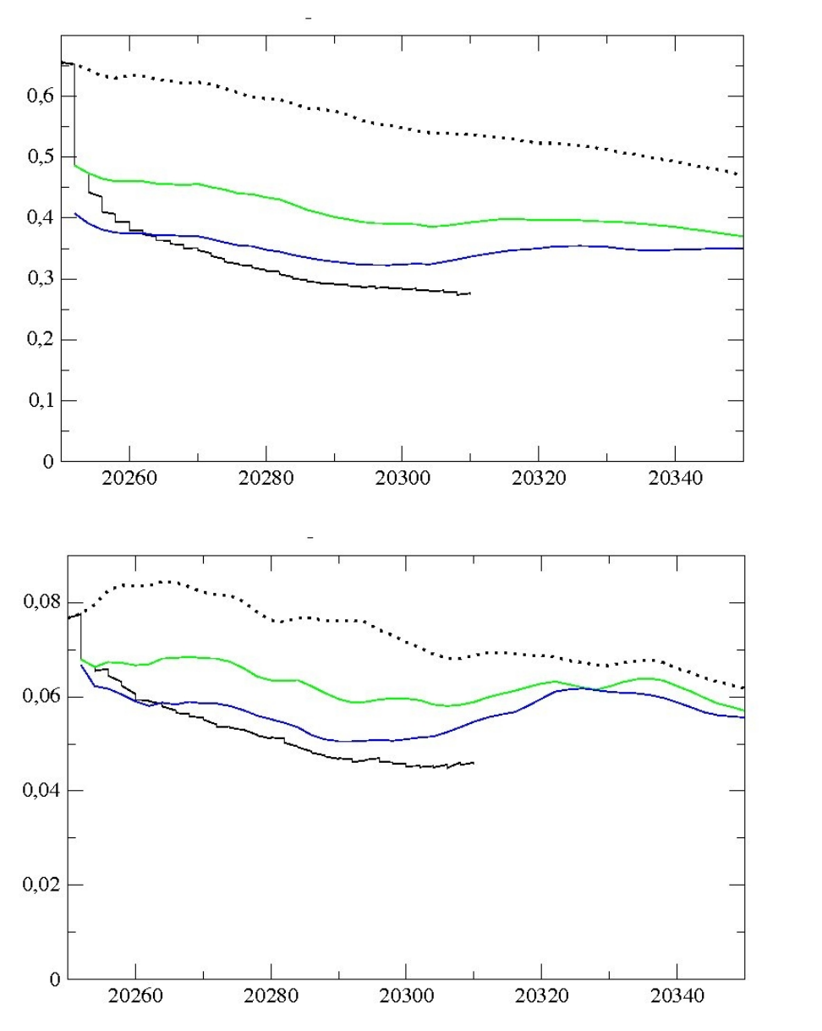


Figure 7 shows the RMS error for the temperature (top) and the meridonal velocity (bottom). The dashed line correspond to the false run, the full black line is the filtered solution, the green line is the free run initialised with the filtered solution and the blue line is the free run initialised with the smoothed solution.

Conclusion

The smoother has been successfully implemented in a realistic ocean circulation configuration. It has shown strong skills to use more efficiently observations scattered in time, like satellite tracks of SSH. Reanalyses from the smoother are more realistic and consistent than the ones from a filter. The residual error from the smoother analysis is lower as we have seen in results II.1. Another aspect of the improvements is the spatially smoothed solution that prevent inconsistent structures (results II.2). Finally, we saw in results II.3 that the dynamics in the smoothed solution is closer to the reference than the one from the filtered solution.

When observations are quite dispersed in time or space, the smoother is a usefull tool to extend the influence of subsequent observations to the past and then improve the coverage of the observations for reanalysis purposes. It uses the observations in an optimal way, introducing temporal correlations (compare to the filter that only use spatial correlations). In conclusion, we strongly recommend to implement smoothers to get more realistic and coherent reanalysis.

Références :

Cosme E., J.-M. Brankart, J. Verron, P. Brasseur, M. Krysta, Implementation of a Reduced-rank, square-root smoother for ocean data assimilation, Ocean Modelling, 33, 87-100, 2010.
Pham, D. T., J. Verron, and M. C. Roubaud, A singular evolutive extended Kalman filter for data assimilation in oceanography, J. Marine. Sys., 16 , 323-340, 1998.